SYNOPTIC INVESTIGATION OF EAST COAST "BACK-DOOR" COLD FRONTS

Gordon Allen Bellemer

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THESIS

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by

Gordon Allen Bellemer

Thesis Advisor: M. S. Tracton

December 1973

T157011

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Synoptic Investigation of East

Coast "Back-Door" Cold Fronts

by

Gordon Allen Bellemer
Lieutenant, United States Navy
B.A., Rhode Island College, 1968

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Results are presented from a synoptic study of "back-door" cold fronts along the east coast of the United States in the years 1963 to 1972. The investigation sets forth the climatology of back-door cold fronts with respect to: 1) frequency, 2) six hourly speed of movement, and 3) southern penetration. The individuality of fronts is treated with respect to: 1) temperature and dew-point changes, 2) pressure tendencies, 3) windshifts, 4) precipitation, 5) vertical extent, and 6) surface/500-mb relationships. Findings include: 1) highest frequency of occurrence is late spring and early fall, 2) speed of movement is greatest in nighttime hours and in spring and fall, 3) deep southern penetration is most likely to occur in June, 4) precipitation is more associated with a 500-mb short-wave trough and position and/or motion of the surface front, 5) fronts continue southward penetration until parallel to 500-mb flow and 6) southernmost penetration of fronts is coincident with movement of the high center behind (i.e., north of) the front eastward off the coast. A detailed discussion of the 2 April 1963 case is presented.

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ACKNOWLEDGEMENTS

The author wishes to thank Professor M. S. Tracton, faculty advisor, for his guidance throughout this study.

Appreciation is extended to the Environmental Prediction Research Facility, Monterey, California, for the use of data and facilities, and to the Naval Weather Service Environmental Detachment, Asheville, North Carolina, for promptly supplying the necessary data.

My deepest appreciation goes to my wife, Marilyn, and family for tolerating my bad humor for the past few months.

I. INTRODUCTION

A. BACKGROUND AND OBJECTIVES

Several times each year, cold fronts over the extreme eastern United States move toward the southwest, frequently bringing a much needed relief from hot humid conditions in coastal states. These fronts are known colloquially as "back-door" cold fronts, the term "back-door" denoting the fact that the cold fronts have a component of motion toward the west (e.g., Figure 1) rather than the more normal movement with a component toward the east. The cold air associated with back-door cold fronts is maritime polar (mP) or modified continental polar (cP) air which streams down the east side of an anticyclone migrating across central Canada.

The southward penetration of back-door cold fronts varies from just south of Caribou, Maine to south of Jacksonville, Florida. After achieving their southernmost penetration, the fronts usually return northward along the coast as warm fronts.

The purpose of this research is twofold. First, the general climatology of back-door cold fronts is documented with respect to: 1) frequency, 2) speed of movement, and 3) southern penetration. Secondly, the individuality of the fronts is assessed with respect to: 1) temperature

Figure 1. Surface analyses, 1800 GMT 18, 19, 20 September 1967.

and dew-point changes, 2) precipitation, 3) pressure changes, 4) windshifts, 5) vertical extent and slope, and 6) associated 500-mb contour patterns. The study described herein considers all cold fronts which moved toward the south and west along the east coast of North America south of 50 deg North latitude for the ten-year period 1963 to 1972. The basic approach is a synoptic investigation utilizing conventional meteorological data.

B. PREVIOUS RESEARCH

Previous research of back-door cold fronts has been limited, primarily because of a lack of excitement on the part of the synoptic meteorologist about this relatively uninteresting phenomena (i.e., uninteresting compared to such phenomena as Atlantic East Coast cyclogenesis). Nevertheless, back-door cold fronts are significant features of the weather along the East Coast and, therefore, are a worthy subject of investigation. Most previous research of back-door cold fronts has been concerned with climatology and avoided discussions of the individual characteristics of the fronts. One exception, Carr (1951), considered one case (16 May 1951) which penetrated southward to the coast of Georgia. He noted that an eastward moving "V" shaped cold trough, immediately adjacent to the Atlantic coastal region, was associated with the surface cold front. Winds at 500 mb along the coast were from the northwest.

A climatological study by Hovey, Sirinek and Storer (1967) considered only those fronts which moved south of Portland, Maine and had a westerly component to their movement. This study, consisting of 39 cases for the nine-year period 1956 to 1964, found a maximum frequency of occurrence in September and a secondary maximum in the combined months of May and June. The main features at 500 mb were a closed high or pronounced ridge to the west of the New England states, usually over the lower Ohio Valley or extending northward to Hudson Bay in Canada. An average two-day duration of mP air in New England was noted, with a maximum duration of five days. The average rate of movement of the cold front was found to be 3° latitude for 12 hours, with a maximum of 5° per 12 hours. Also noted was the fact that only three of 39 cases stalled between Portland and Boston.

Bosart, Pagnotti, Lettau (1973) considered cases for which an approximately east-west oriented front was first observed north of 45N and whose lifetime exceeded 24 hours. Cases were restricted to the seven-month period April through October of the years 1964 through 1971. They noted the maximum southward penetration and maximum frequency of occurrence was in June. More than half the cases had a trace or less of precipitation, and temperature changes following frontal passages decreased from north to south.

C. DATA AND METHODS

Data used in this research were 10 years of microfilmed National Meteorological Center (NMC) six hourly surface analyses. These analyses were surveyed for cases meeting the prescribed criteria for back-door cold fronts. After the cases were selected, corresponding NMC 500-mb height analyses were scanned to determine the general configuration of the 500-mb flow, and a selected month's (June) charts were collected for more detailed investigation of relationships between surface and 500-mb patterns. All the above charts were furnished through the courtesy of the Navy Environmental Prediction Research Facility, Monterey, California.

Data utilized to deduce local parameter changes for individual cases include surface hourly observations from 40 stations over the eastern United States and Canada (Figure 2, Table I), upper-air data from eight stations (Figure 2), and the United States Department of Commerce Climatological Data and Hourly Precipitation Data. Also utilized for ascertaining associated precipitation patterns were the Radar Summary charts prepared by the National Severe Storms Center, Kansas City, Missouri. The above data was obtained from the Naval Weather Service Environmental Detachment, Asheville, North Carolina.

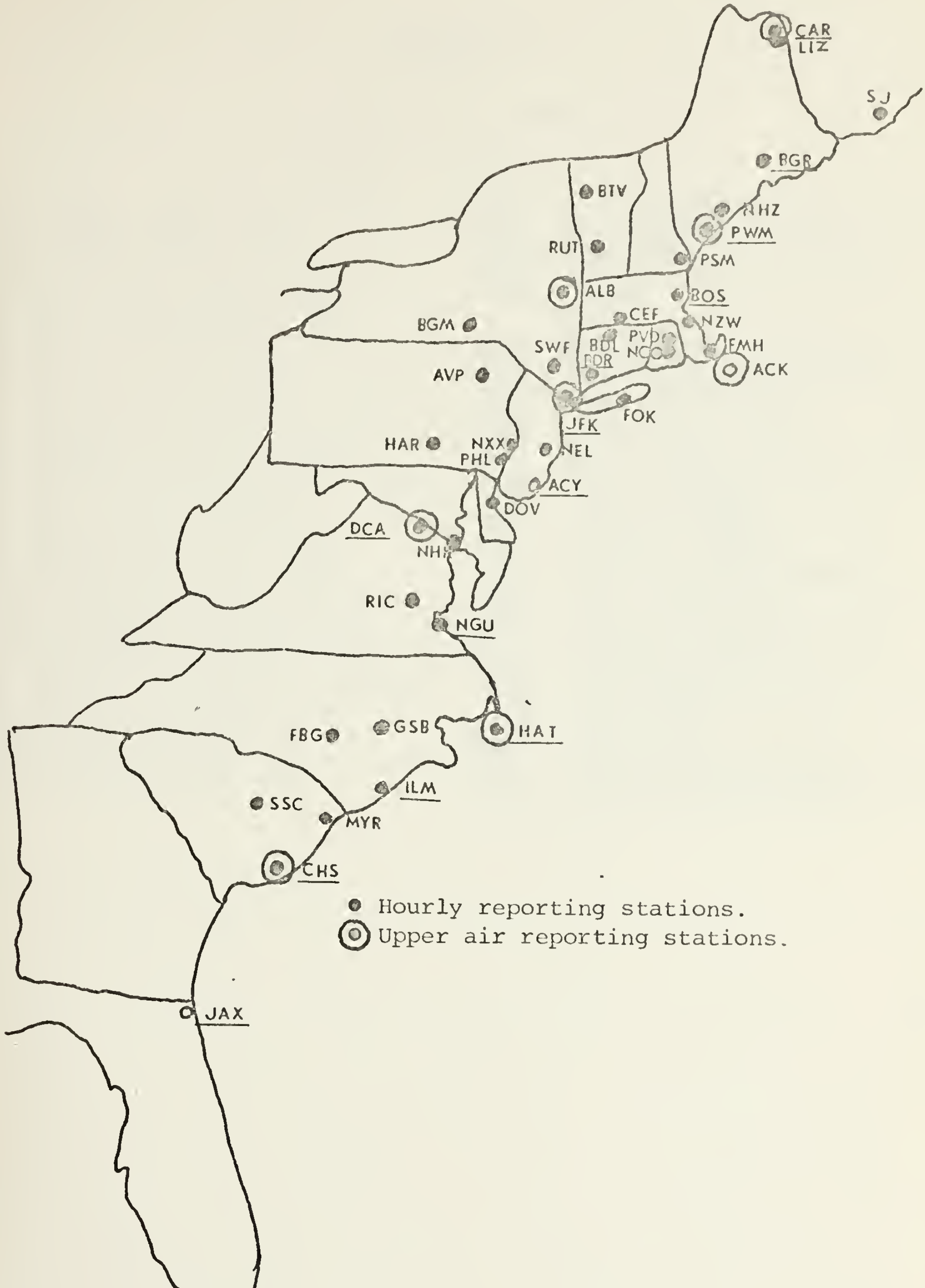

Figure 2. Station locator.

TABLE I

Station identifier.

SJ	Saint John AP, Canada	JFK	N.Y. Kennedy WSO AP, N.Y.
LIZ	Loring AFB, ME	BGM	Binghamton WSO AP, N.Y.
CAR	Caribou WSO AP, ME	NEL	NAS Lakehurst, N.J.
BGR	Dow AFB, Bangor, ME	AVP	W.Barre Scranton WSO AP, N.Y.
NHZ	NAS Brunswick, ME		
PWM	Portland WSO AP, ME	NXX	NAS Willow Grove, PA
PSM	Pease AFB, N.H.	PHL	Philadelphia WSO AP, PA
BTV	Burlington WSO AP, VT	HAR	Harrisburg FAA AP, PA
RUT	Rutland, VT	DOV	Dover AFB, Del.
BOS	Boston WSO AP, Mass.	DCA	Washington, WSO AP, D.C.
NZW	NAS South Weymouth, Mass.	NHK	NAS Patuxent River, MD
FMH	Otis AFB, Mass.	RIC	Richmond WSO AP, VA
ACK	Nantucket AP, Mass.	NGU	Norfolk WSO AP, VA
CEF	Westover AFB, Mass.	HAT	Cape Hatteras WSO, N.C.
PVD	Providence WSO AP, R.I.	NKT	MCAS Cherry Pt, N.C.
NCO	FLEWEAFAC Quonset Pt, R.I.	GSB	Seymour-Johnson AFB, N.C.
BDL	Hartford WSO AP, Conn.	FBG	Simmons AAF, N.C.
BDR	Bridgeport WSO AP, Conn.	ILM	Wilmington WSO AP, N.C.
ALB	Albany WSO AP, N.Y.	SSC	Shaw AFB, S.C.
SWF	Stewart AFB, N.Y.	MYR	NWSO Myrtle Beach, S.C.
FOK	Suffolk AFB, N.Y.	CHS	Charleston WSO AP, S.C.
		JAX	Jacksonville WSO AP, Fla.

II. CLIMATOLOGY

A. GENERAL SYNOPTIC SITUATION

Generally, the surface synoptic situation at the onset of "backdooring" (i.e., progression of a back-door cold front down the coast) featured an east-west oriented front north of 40N. A high pressure center was located in central to eastern Canada with a ridge axis oriented from the high center to the Canadian/United States border east of the Great Lakes (Figure 3). At the 500-mb level a ridge was located over the Great Lakes region while a north-south oriented 500-mb long-wave trough east of the Atlantic coast (Figure 3). The 500-mb flow along the coast was northwesterly. In more pronounced cases of back-door cold fronts, a 500-mb short-wave trough was imbedded in the northwesterly flow in advance of the ridge.

During the life of the back-door cold front, from the onset of "backdooring" until southernmost penetration, the long-wave 500-mb ridge moved gradually east. The movement of the surface high and, consequently, the movement of the front was closely related to the strength of the 500-mb ridge. A more intense ridge implies a stronger surface high, a more southerly direction to its movement, and an increased southward penetration of the back-door cold front. Generally, coincident with southernmost penetration of the

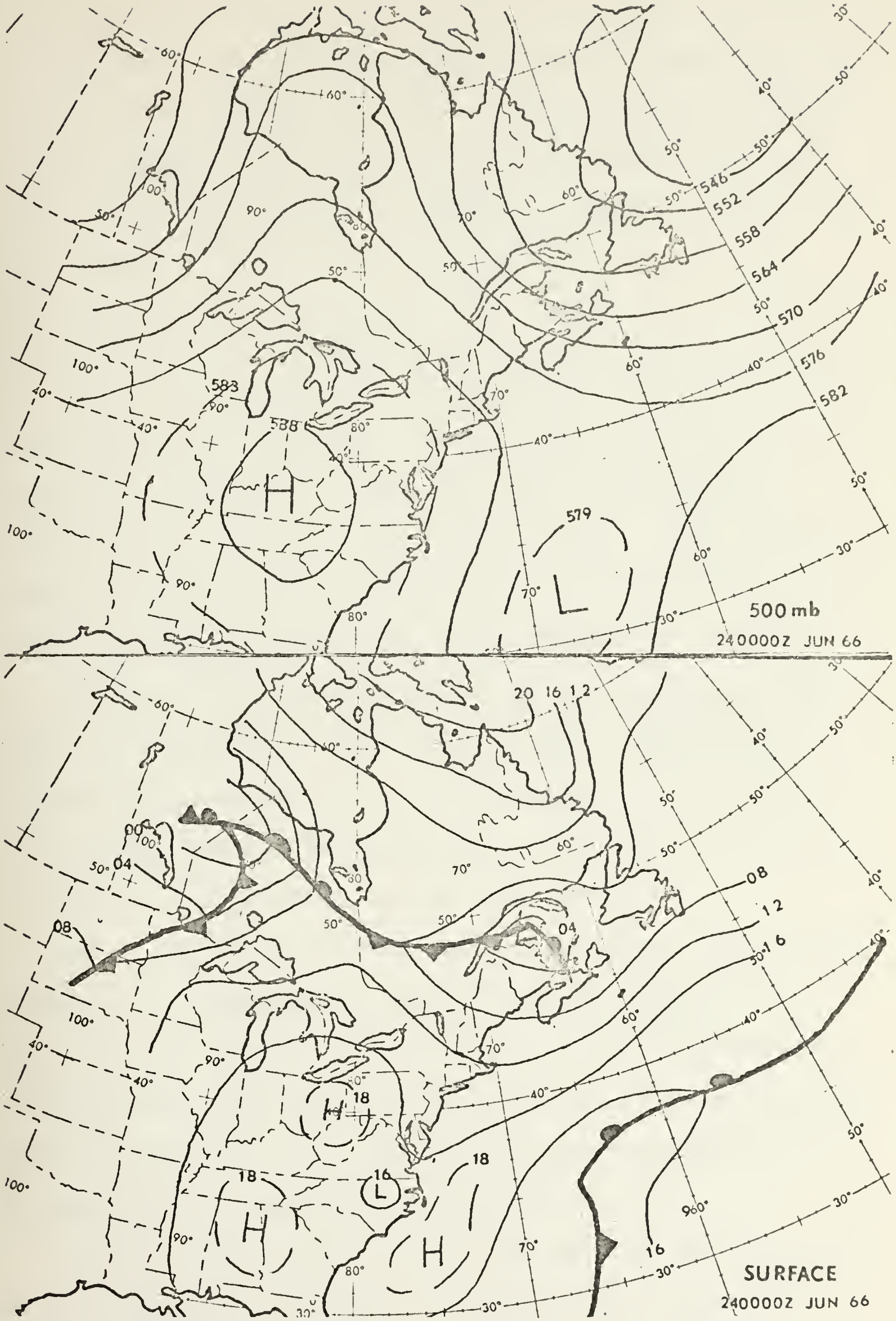

Figure 3. 500 mb and surface analyses, 0000 GMT 24 June 1966.

fronts was movement of the surface high center eastward off the coast. Following a brief period during which the front remained stationary at the position of its southernmost penetration, the eastward movement of the high permitted the front to return northward along the coast as a warm front.

B. FREQUENCY OF OCCURRENCE

In the ten-year period examined, 83 cases of back-door cold fronts were observed. Table II lists the dates of the cases, the dates referring to the commencement of "backdooring" as gleaned from NMC analyses. The maximum number of cases for any year was 14 in 1963, while a minimum of four occurred in 1965, 1970, and 1972.

Table III shows the frequency of occurrence by month. Cases were observed in all months, with a maximum of 13 occurrences in October, and a secondary maximum in June. The minimum monthly total was one, occurring in each of the months of December, January and February.

Table IV lists the frequency of back-door cold frontal passages at 12 selected stations and the frequency at which fronts commence "backdooring" south of the stations. The stations (underlined in Figure 2) range from Caribou, Maine to Jacksonville, Florida with approximately equal spacing between intermediate stations.

Table IV shows that a maximum number of back-door cold frontal passages occurred at Bangor, Maine, while the

TABLE II. Back-door cold front cases.

1.		2 Apr	29.		26 May	56.	1969	16 Mar
2.		9 May	30.		7 Jun	57.		8 Apr
3.		1 Jun	31.	1966	27 Apr	58.		26 Apr
4.		7 Jun	32.		24 Jun	59.		14 Aug
5.		9 Jun	33.		8 Aug	60.		26 Aug
6.		25 Jun	34.		28 Aug	61.		30 Aug
7.		27 Jun	35.		2 Sep	62.		6 Sep
8.		1 Jul	36.		11 Sep	63.		13 Sep
9.		24 Jul	37.		19 Sep	64.		6 Oct
10.		22 Aug	38.	1967	21 Jan	65.	1970	27 Apr
11.		15 Oct	39.		10 Feb	66.		23 May
12.		16 Oct	40.		10 Mar	67.		29 Jul
13.		16 Nov	41.		17 May	68.		22 Sep
14.		27 Nov	42.		10 Jun	69.	1971	5 Jun
15.	1964	27 Apr	43.		6 Sep	70.		13 Jun
16.		4 May	44.		19 Sep	71.		26 Jun
17.		8 May	45.		4 Oct	72.		17 Aug
18.		1 Jul	46.	1968	14 Apr	73.		31 Aug
19.		16 Jul	47.		25 May	74.		5 Sep
20.		20 Jul	48.		6 Jun	75.		2 Oct
21.		2 Aug	49.		13 Jul	76.		16 Oct
22.		13 Oct	50.		16 Jul	77.		19 Oct
23.		27 Oct	51.		4 Aug	78.		30 Oct
24.		2 Nov	52.		7 Aug	79.		27 Dec
25.		8 Nov	53.		13 Oct	80.	1972	2 Mar
26.		24 Nov	54.		17 Oct	81.		1 May
27.	1965	1 May	55.		19 Oct	82.		23 May
28.		10 May				83.		18 Jul

TABLE III. Frequency of back-door cold fronts by month for the ten-year period 1963-1972.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Frequency	1	1	3	7	11	12	9	11	9	13	5	1

TABLE IV. Frequency of back-door cold frontal passages and station-to-station frequency of frontal progression.

	Frequency of FROPA Observed	Number of Fronts Commenced South of	Frequency of Frontal Progression STATION											
			BGR	PWM	BOS	BDR	JFK	ACY	DCA	NGU	HAT	ILM	CHS	JAX
CAR	29	54	25 / 86%	20 / 69%	15 / 52%	11 / 38%	8 / 28%	6 / 21%	3 / 10%	3 / 10%	2 / 7%	1 / 3%	0	
BGR	59	20		51 / 86%	45 / 76%	36 / 61%	31 / 53%	21 / 36%	8 / 14%	7 / 12%	3 / 5%	1 / 2%	0	0
PWM	53	18			47 / 89%	37 / 69%	32 / 60%	22 / 42%	9 / 17%	7 / 13%	3 / 6%	1 / 2%	0	0
BOS	56	9				44 / 79%	36 / 64%	27 / 48%	13 / 23%	11 / 20%	6 / 11%	3 / 5%	1 / 2%	0
BDR	49	4					42 / 86%	32 / 65%	17 / 35%	15 / 31%	8 / 16%	5 / 10%	2 / 4%	1 / 2%
JFK	42	4						32 / 76%	17 / 40%	15 / 36%	8 / 19%	5 / 12%	2 / 5%	1 / 2%
ACY	36	0							20 / 56%	17 / 47%	10 / 28%	5 / 14%	2 / 6%	1 / 3%
DCA	20	0							*	17 / 85%	10 / 50%	5 / 25%	2 / 10%	1 / 5%
NGU	17	0									10 / 59%	5 / 29%	2 / 12%	1 / 6%
HAT	10	0										5 / 50%	2 / 20%	1 / 10%
ILM	5	0											2 / 40%	1 / 20%
CHS	2	0												1 / 50%
JAX	1	0												

*2 cases passed NGU prior to passing DCA.

minimum occurred at Jacksonville. Obvious is the fact that frequency of occurrence decreases from north to south along the coast except between Portland, Maine and Boston, Massachusetts. Only 29 out of 83 cases commenced north of Caribou, and no fronts commenced south of Atlantic City, New Jersey. The largest number of fronts, 34, commenced "backdooring" between Caribou and Bangor.

C. SOUTHERN PENETRATION

The southern penetration of fronts was assessed for the 12 stations referred to above. Results appear in Table IV in terms of the likelihood of frontal passage through a given station if the front passed through stations to the north. For example, of the 53 back-door frontal passages observed at Portland, 47 (89%) of the fronts also passed Boston. In other words, only six of the 53 fronts passing through Portland stalled between Portland and Boston. The high correlation between frontal passages at these two cities was also noted by Hovey, et al (1967). Note also that, of the 53 frontal passages at Portland, only 3 (6%) of the fronts progressed as far south as Cape Hatteras, North Carolina.

In a monthly breakdown of southernmost penetration, the two fronts that passed south of Charleston, South Carolina occurred in August. However, only two out of the 11 August cases penetrated south of Cape Hatteras, while six of the 12 June cases passed the Cape. Although the

southernmost penetration occurred in August, June has the highest expectation of deep southern penetration.

An additional point of interest evident in Table IV is the passage of two fronts through Norfolk, Virginia prior to the frontal passage at Washington, D. C. These were examples of extreme "backdooring" in terms of westerly movement of approximately north-south oriented fronts.

D. SPEED OF MOVEMENT

Speed of movement was determined on the basis of the six hourly positions of fronts along the coast. It should be noted that frontal speeds were deduced from NMC surface analyses alone, and, therefore, the speeds are dependent upon the accuracy of the analyses.

The average speed over six-hour intervals was 11.7 knots, or about 1.2° latitude per six hours. Table V presents a breakdown of speeds for the four standard six-hour synoptic periods (0000-0600 GMT, 0600-1200 GMT, etc.). Note the higher speeds occur during nighttime rather than daytime hours.

Figure 4 presents a graph of average frontal speed vs. month of the year. December, January, and February were combined because of the small number of cases occurring in these months. Note the bimodal distribution for speed vs. month, with relative and absolute maxima occurring in April (1.3° latitude per six hours) and October (1.5° latitude per six hours), respectively. The relative and

TABLE V. Six hourly movements by time period.

		Sample Size	Average speed of movement (°lat/6 hrs)	Maximum speed of movement (°lat/6 hrs)
0000-0600	1900-0100	123	1.3	5.0
0600-1200	0100-0700	124	1.5	5.2
1200-1800	0700-1300	124	.9	3.0
1800-0000	1300-1900	123	1.0	3.6

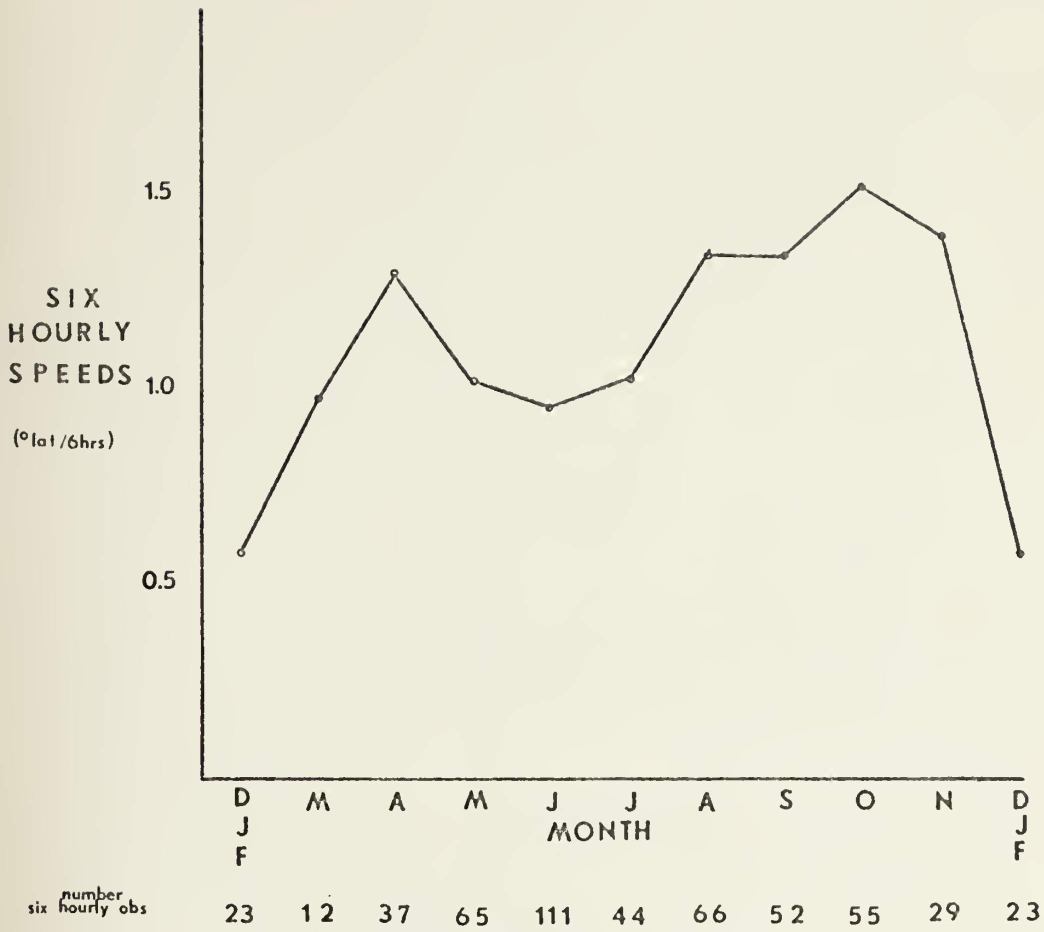

Figure 4. Six hourly speeds of movement by month.

absolute maxima occurred in June (0.9° latitude per six hours) and in the winter months (0.6° latitude per six hours). Thus, the fronts appear to have greater speeds in spring and fall than in summer and winter.

III. PARAMETER CHANGES AND PRECIPITATION

A. CASE SELECTION CRITERIA

From the total sample of 83 cases, ten (underlined in Table I) were selected for detailed analyses of parameter changes across the fronts and of precipitation associated with the fronts. Selection of the case studies was based upon the southern penetration (front must have passed at least through New England) and upon subjective assessment of pronounced situations of "backdooring." Following a more detailed evaluation of all data available, the cases of 13 October 1968 and 19 October 1971 were deleted from further considerations except for precipitation analyses. The deletions were based upon the subtleness of frontal passage as manifest in individual station observations.

B. TEMPERATURE

1. Change in Daily Maximum and Minimum Temperature

The changes in daily maximum and minimum temperatures were defined as the differences in daily maximum and minimum temperatures recorded prior to and following frontal passage. The days used to define "prior to" and "following" were as follows:

	Daily Maximum	
Time of FROPA (EST)	"Prior To"	"Following"
before 1000	day before FROPA	day of FROPA
after 1400	day of FROPA	day after FROPA
1000-1400	day before FROPA	day after FROPA

Time of FROPA(EST)	Daily Minimum "Prior To"	"Following"
before 2200	day before FROPA	day of FROPA
after 0200	day of FROPA	day after FROPA
2200-0200	day before FROPA	day after FROPA

Table VI lists the average and extreme changes recorded at each of the 29 selected stations. The extreme changes in maximum temperature were a 34F decrease at both Westover AFB, Massachusetts, and Hartford, Connecticut, and a 2F increase at Caribou. The latter figure was the only rise in daily maximum temperature observed and apparently was the result of north-south fluctuations of the front over the station for approximately 48 hours prior to the front decisively continuing its southward progression.

Changes in the daily minimum temperatures were less in magnitude. Generally, temperature decreases were observed; however, several stations did observe higher minimum temperatures following frontal passage. The most likely cause for higher minimum temperatures was an increase in cloudiness behind the front, a phenomenon that surpressed radiational cooling. The extreme values of the changes were a 13F decrease at Burlington, Vermont, and an 8F rise also at Burlington.

Note from Table VI the greatest maximum temperature changes were recorded at inland stations as opposed to coastal stations. As an example, in the 6 June 1968 case, Hartford, Connecticut recorded a decrease in its

TABLE VI. Daily temperature changes. (°F)

STA	# Cases	Average Change in Daily Maximum Temperature	Extremes		Average Change in Daily Minimum Temperature	Extremes	
CAR*	6	- 8.3	-17	+ 2	- 5.2	-10	0
BGR	8	-17.6	-25	- 7	- 5.8	-10	-2
NHZ	8	-16.4	-25	- 2	- 5.4	-10	0
PWM	8	-15.9	-29	- 1	- 5.0	-10	+4
PSM	8	-20.4	-28	-11	- 4.0	- 9	0
BTV	7	- 6.0	-16	- 2	- 2.9	-13	+8
BOS	8	-18.9	-28	-10	- 5.3	-12	0
NZW	8	-19.6	-33	- 5	- 4.5	- 8	-1
FMH	8	-12.1	-24	- 2	- 2.5	- 8	+5
CEF	8	-17.1	-34	- 2	- 3.4	- 8	-1
PVD	8	-17.3	-30	- 9	- 4.4	-11	-1
NCO	8	-18.1	-27	- 9	- 3.8	- 9	-1
BDL	8	-16.5	-34	- 4	- 5.2	- 9	-2
BDR	8	-10.6	-19	- 3	- 2.5	- 6	+1
ALB	5	-13.6	-31	0	- 1.6	- 9	+7
SWF	4	-14.8	-20	- 2	- 6.3	-15	-1
FOK	4	-14.3	-17	-10	- 1.8	- 6	+1
JFK	5	- 9.2	-14	- 5	- 1.6	- 4	-1
BGM	2	-10.0	-11	- 9	- 3.0	- 8	+2
NEL	6	- 9.5	-14	- 4	- 5.2	-11	+1
NXX	6	-10.1	-19	- 2	- 0.8	- 3	+2
PHL	4	-13.0	-18	- 5	- 2.3	- 4	-1
AVP	3	-13.0	-16	- 8	- 1.7	- 4	+1
HAR	2	-12.5	-14	-11	- 2.0	- 3	-1
DOV	4	-12.3	-22	- 1	- 3.0	- 8	+1
DCA	2	- 9.0	-10	- 8	- 3.5	- 6	-1
NHK	2	- 8.5	- 9	- 8	- 5.5	- 7	-4
NGU	1		-7			-4	
RIC	1		-3			+4	

*Includes data from LIZ

daily maximum of 34F while Bridgeport, Connecticut recorded a decrease of 18F. This reflects the generally greater variability of temperatures at inland stations as opposed to coastal stations where the moderating influence of the water is operative.

2. Temperature Change Across Fronts

The temperature change across fronts was defined as the difference between the temperature at the hour of frontal passage at a given station and the temperature two hours later. Table VII lists the results of this study.

The largest and smallest two-hour temperature changes were a 24F decrease at Willow Grove, Pennsylvania and a 6F rise at Portland and Lakehurst, New Jersey, respectively. The temperature increases were due to weak fronts passing over the stations at the time of maximum diurnal heating. The largest decreases in temperature were in eastern Pennsylvania and western New Jersey. In general, temperature changes across fronts were greatest at inland stations, as was the case for changes in average daily maximum and minimum temperatures.

3. Dew-Point Change Across Fronts

The change in dew-point temperature across fronts was defined in a manner analogous to temperature change. Table VII lists the results of this study. The extremes found were a 13F decrease at Bangor and a 9F rise at Philadelphia. The change in dew-point temperature was

TABLE VII. Temperature changes across fronts. (°F)

STA	# Cases	Average T Change	Extremes		Average T_d Change	Extremes	
CAR*	3	- 4.0	- 6	-3	- 6.0	-11	-2
BGR	7	- 6.6	-11	+4	+ .1	-13	+5
NHZ	7	- 6.3	-12	+3	- 2.7	- 9	+5
PWM	7	- 3.7	-12	+6	- 1.6	- 9	+4
PSM	7	- 5.0	- 9	-2	- 1.7	-10	+3
BTV	5	- 6.8	-12	-3	- 2.2	-10	+1
BOS	7	- 8.3	-14	-4	- 3.6	-11	-1
NZW	7	- 8.1	-16	-3	- 3.9	-10	+2
FMH	7	- 5.3	- 8	-1	- 2.4	- 8	+5
CEF	7	- 8.6	-23	0	- 0.6	-12	+6
PVD	7	- 7.6	-16	-3	- 1.1	- 9	+5
NCO	7	- 9.6	-20	-4	- 2.3	-10	+4
BDL	7	- 6.4	-14	-1	- 2.4	- 9	+3
BDR	7	- 4.7	- 8	0	- 1.6	- 6	+3
ALB	5	- 8.2	-17	-2	- 2.0	- 7	+1
SWF	4	- 7.8	-15	-3	- 1.8	- 6	+2
FOK	4	- 3.5	- 7	+2	0.0	- 5	+3
JFK	5	- 6.4	-16	+3	- .6	- 4	+4
BGM	1		-18			- 5	
NEL	6	- 7.0	-17	+6	- 3.3	- 8	+2
NXX	6	-12.5	-24	-8	- 2.3	- 7	+3
PHL	5	-12.2	-22	-7	- .4	- 4	+9
AVP	1		-13			- 6	
HAR	3	- 9.3	-13	-6	- 3.0	- 6	0
DOV	5	- 7.2	-11	-3	+ .8	- 7	+8
DCA	3	- 5.7	- 7	-2	+ 1.0	- 3	+5
NHK	1		- 6			+ 2	
NGU	1		- 6			+ 6	
RIC	-	-	-		-	-	

*Includes data from LIZ

not as pronounced as the temperature change. This results from the fact that the principal change in dew point did not occur until some seven to eight hours after frontal passage. Typically, the usual sequence in the dew point was a slight rise at the time of frontal passage followed by a noticeable decrease approximately seven to eight hours following passage.

C. PRESSURE CHANGES

The pressure changes accompanying frontal passage at a given station were defined as the three-hour tendency immediately preceding and following the hour of frontal passage. Basically, three categories of pressure tendencies were found: 1) a drop in pressure prior to frontal passage and increasing thereafter, 2) steady pressure prior to passage and increasing pressure thereafter and 3) a rising pressure before passage with a sharper rise thereafter.

Table VIII lists the average magnitude of the changes. The greatest pressure fall prior to passage was 2.2 mb, and the greatest rise after was 4.3 mb.

D. WINDSHIFTS

The nature of windshifts accompanying frontal passage varied from case to case, as well as from station to station. The most characteristic windshift was westerly to northeasterly. However, other variations were observed.

TABLE VIII. Pressure tendencies. (mb)

STA	# Cases	Average 3 Hour Prefrontal	Maximum Fall	Average 3 Hour Postfrontal	Maximum Rise
CAR*	3	-0.1	-0.3	+1.4	+2.2
BGR	6	-0.2	-0.7	+2.5	+4.3
NHZ	6	+0.7	-1.7	+1.9	+3.7
PWM	6	+0.4	-1.4	+2.2	+3.1
PSM	6	-0.2	-1.7	+1.9	+2.5
BTV	6	-0.3	-1.8	+1.2	+1.5
BOS	7	-0.1	-1.4	+1.7	+3.6
NZW	7	-0.3	-2.2	+1.8	+2.9
FMH	7	-0.1	-2.0	+1.3	+3.0
CEF	7	0	-1.3	+2.4	+3.7
PVD	7	-0.1	-1.0	+2.4	+3.7
NCO	7	0	-0.9	+2.1	+3.0
BDL	7	+0.1	-1.0	+1.9	+3.4
BDR	7	+0.1	-1.0	+1.4	+3.0
ALB	6	-0.5	-1.8	+2.1	+3.9
SWF	4	-0.1	-0.3	+1.6	+3.5
FOK	4	+0.4	-0.2	+1.7	+2.3
JFK	5	-0.3	-1.0	+1.1	+1.9
BGM	3	-0.6	-0.7	+1.5	+3.0
NEL	5	-0.1	-1.6	+1.4	+1.9
NXX	4	-0.2	-1.5	+1.2	+3.3
PHL	5	-0.1	-1.4	+1.6	+2.7
AVP	2	-1.1	-1.5	+2.4	+3.1
HAR	2	-0.8	-1.0	+2.5	+3.1
DOV	5	+0.2	-1.3	+1.5	+2.2
DCA	2	-0.1	-0.6	+1.2	+1.3
NHK	2	-0.4	-0.6	+1.1	+1.5
NGU	2	-0.2	-0.3	+1.3	+1.3
RIC	1		-0.3		+1.6

*Includes data from LIZ

Along the coast it was not uncommon to see a windshift from southeasterly (seabreeze) to northeasterly.

Generally, there were little or no variations of wind speed accompanying frontal passage. In a few cases, however, gusty wind conditions were observed immediately following frontal passage.

E. PRECIPITATION

For the purpose of precipitation analyses, frontal precipitation was that which occurred from 12 hours prior to and 24 hours following frontal passage. Precipitation occurring within the latter period that was subjectively assessed to be associated with the returning warm front was not considered.

Table IX summarizes the results of the precipitation study. It is not possible to ascribe a meaningful average amount to the back-door cold fronts because of the extreme variability from case to case and from station to station. The maximum values, as would be expected, occurred in mountainous areas. For all cases in which precipitation occurred at coastal stations, relative maxima were located between Portland and New York City.

The observed precipitation ranged from light drizzle to violent thunderstorms. It should be noted that the major areas of precipitation, as was evident from the Radar Summary charts and the "Remarks and Supplemental Coded Data" column of the hourly observations, appeared to be

TABLE IX. Precipitation.

STA	Number Cases	Number Cases with Precipitation (including trace)	Maximum Amount (inches)
CAR	6	3	.32
BGR	9	5	.30
NHZ	9	5	*.40
PWM	9	4	.89
PSM	9	4	.45
BTV	9	4	*.66
BOS	10	5	.67
NZW	10	5	.42
FMH	10	5	.28
CEF	10	6	*.33
PVD	10	5	.20
NCO	10	6	.26
BDL	10	6	.06
BDR	10	3	.06
ALB	8	5	*.21
SWF	5	2	T
FOK	5	3	.05
JFK	8	3	.07
BGM	3	2	1.57
NEL	7	2	T
NXX	7	3	T
PHL	7	3	T
AVP	1	0	
HAR	1	0	
DOV	7	2	.01
DCA	3	2	.27
NHK	2	0	
NGU	2	0	
RIC	1	0	

*Precipitation which continues to fall beyond the 24-hour limitation following frontal passage is not considered.

associated more with the short-wave trough at 500 mb than to the position or motion of the surface front. That is, the relationship between the areas of precipitation and frontal position and motion varied considerably from case to case, but the areas of precipitation were consistently related in the expected manner to the 500-mb short-wave trough.

F. VERTICAL EXTENT AND SLOPE

To determine the vertical extent and slope of fronts space-height cross sections of temperature and potential temperature along a line connecting Caribou and Charleston were constructed from appropriate 0000 and 1200 GMT soundings. Vertical extent was defined as the top of the frontal inversion. The slope was defined as the slope of the shortest line connecting the surface front and the top of the frontal inversion at a given station. For each case, an average slope was obtained by averaging the slopes deduced for several upper air stations during the life of the front.

The results of the above mentioned analyses indicate that the fronts were quite shallow, with the maximum vertical extent ranging from 5000 to 7000 ft. The average slopes ranged from 1/300 to 1/400.

IV. SURFACE/500-MB RELATIONSHIPS

The 12 June cases were selected for assessing relationships between the surface features associated with back-door cold fronts and the accompanying 500-mb patterns. Selection of the June cases was based upon the high frequency of occurrence of back-door cold fronts in June and the greater variability of southernmost penetration than in any other month.

The first notable observation was the relationship between the motion of the surface highs and the southern penetration of fronts and, in turn, the relationship between the motion of the surface highs and the 500-mb patterns. It was observed that motion of the surface highs toward the south to south-southwest produced farther southern penetration than motion toward the east and southeast. The motion of the surface high, in turn, was directly related to the 500-mb contours. More specifically, the movement of the high was approximately in the same direction as the 500-mb flow at the position of the high center, so that flow to the south at 500 mb resulted in a greater southward displacement of fronts than flow to the southeast. Figures 5 and 6 serve to illustrate these relationships.

Another notable observation was that eastward movement of the high off the coast was coincident with the

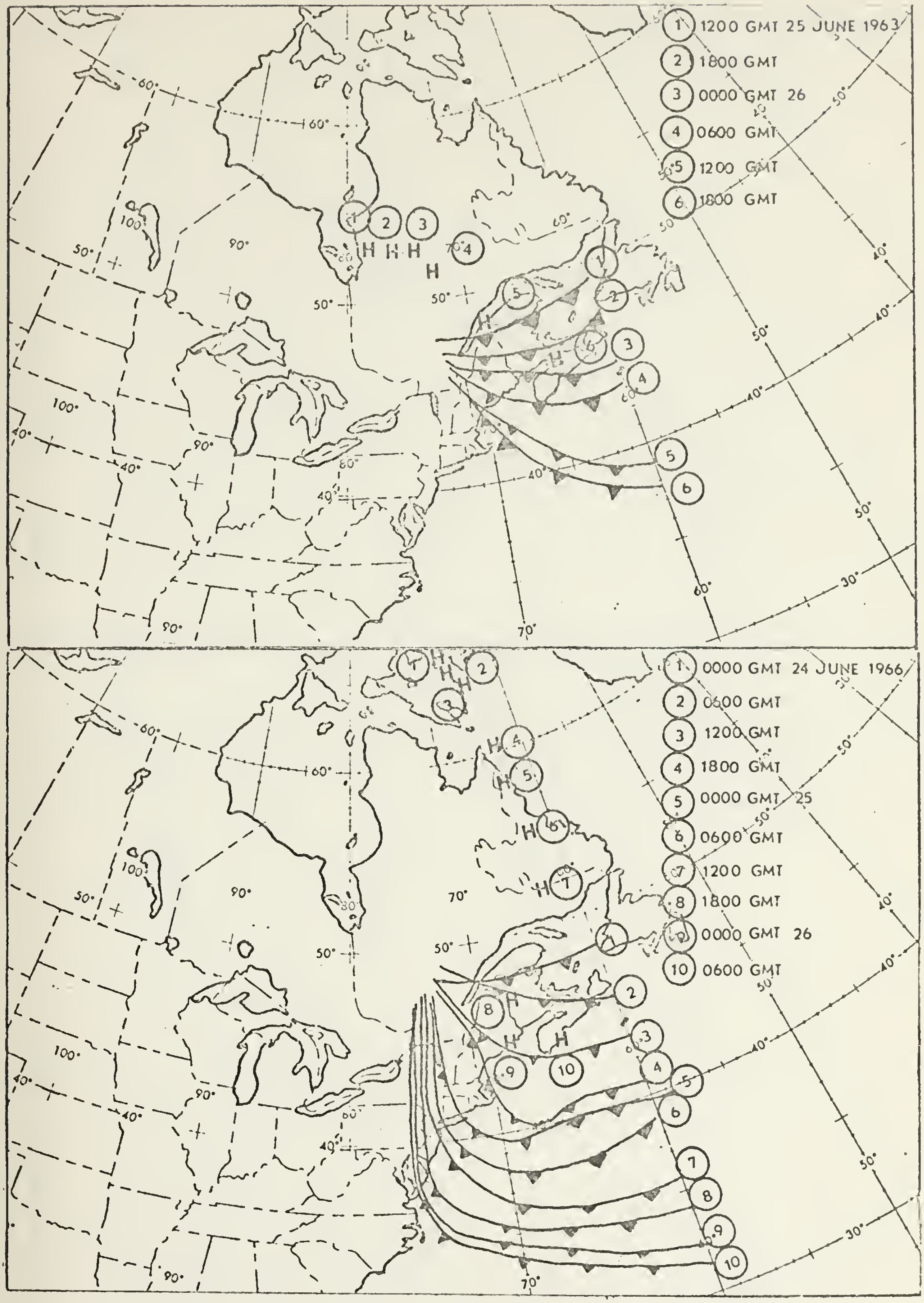

Figure 5. Relative position of back-door cold fronts and associated surface highs for the cases of 25 June 1963 and 24 June 1966.

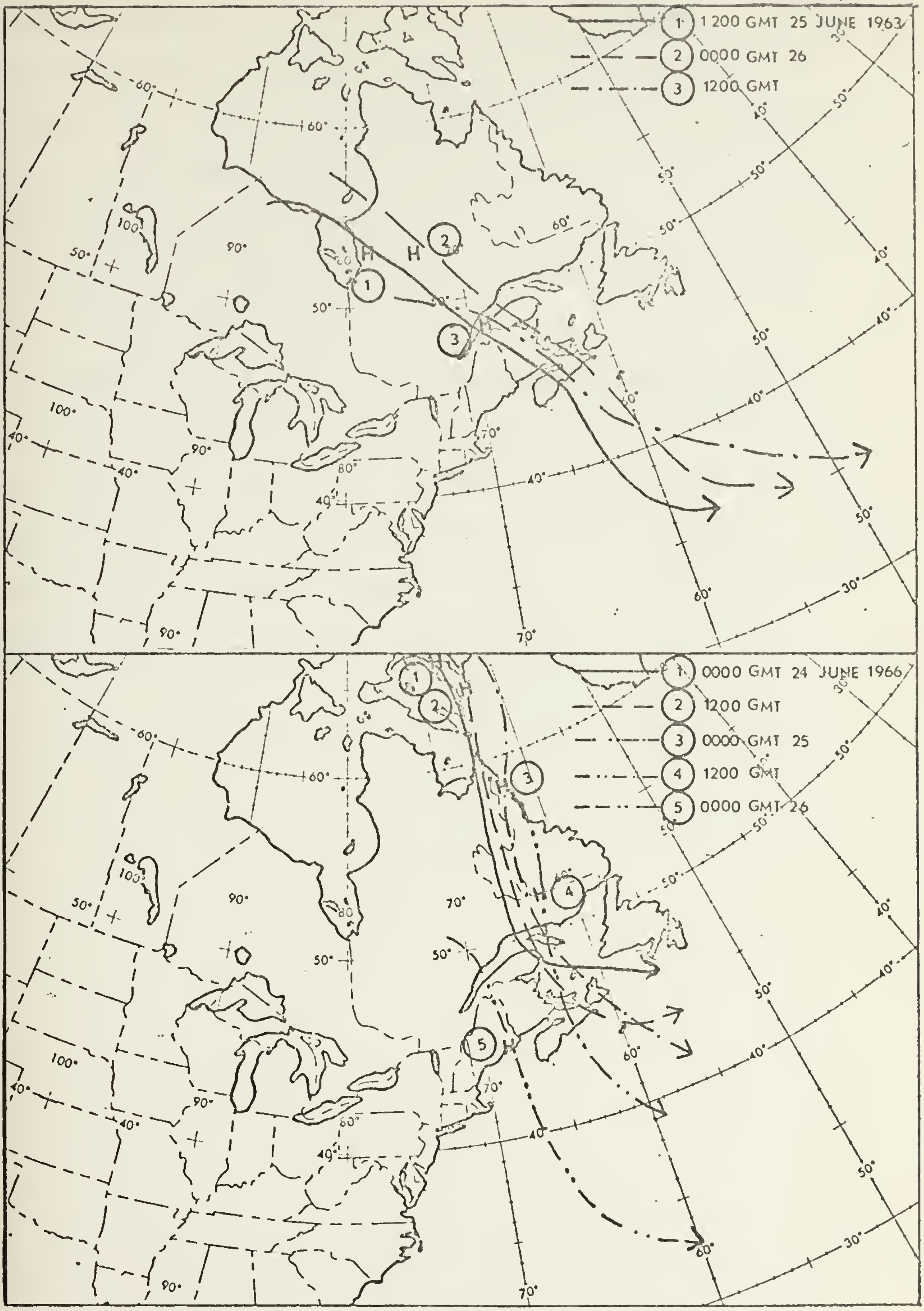

Figure 6. Relative position of the surface highs associated with back-door cold fronts and 500-mb flow for the cases of 25 June 1963 and 24 June 1966.

southernmost penetrations of the fronts. Figure 5 exemplifies this result. Prior to 0000 GMT 26 June 1966, the motion of the high was in a general southerly direction, whereas from 0000 to 0600 GMT 26 June the high moved in an east-southeasterly direction. During this latter period, the frontal position along the coast became stationary after southernmost penetration.

Finally, it is to be noted that southern penetration continued until fronts became parallel to the 500-mb contours from the ridge line to about 300 miles off the coast. When fronts became parallel to the 500-mb contours, southernmost penetration was achieved. Figure 7 illustrates this observation.

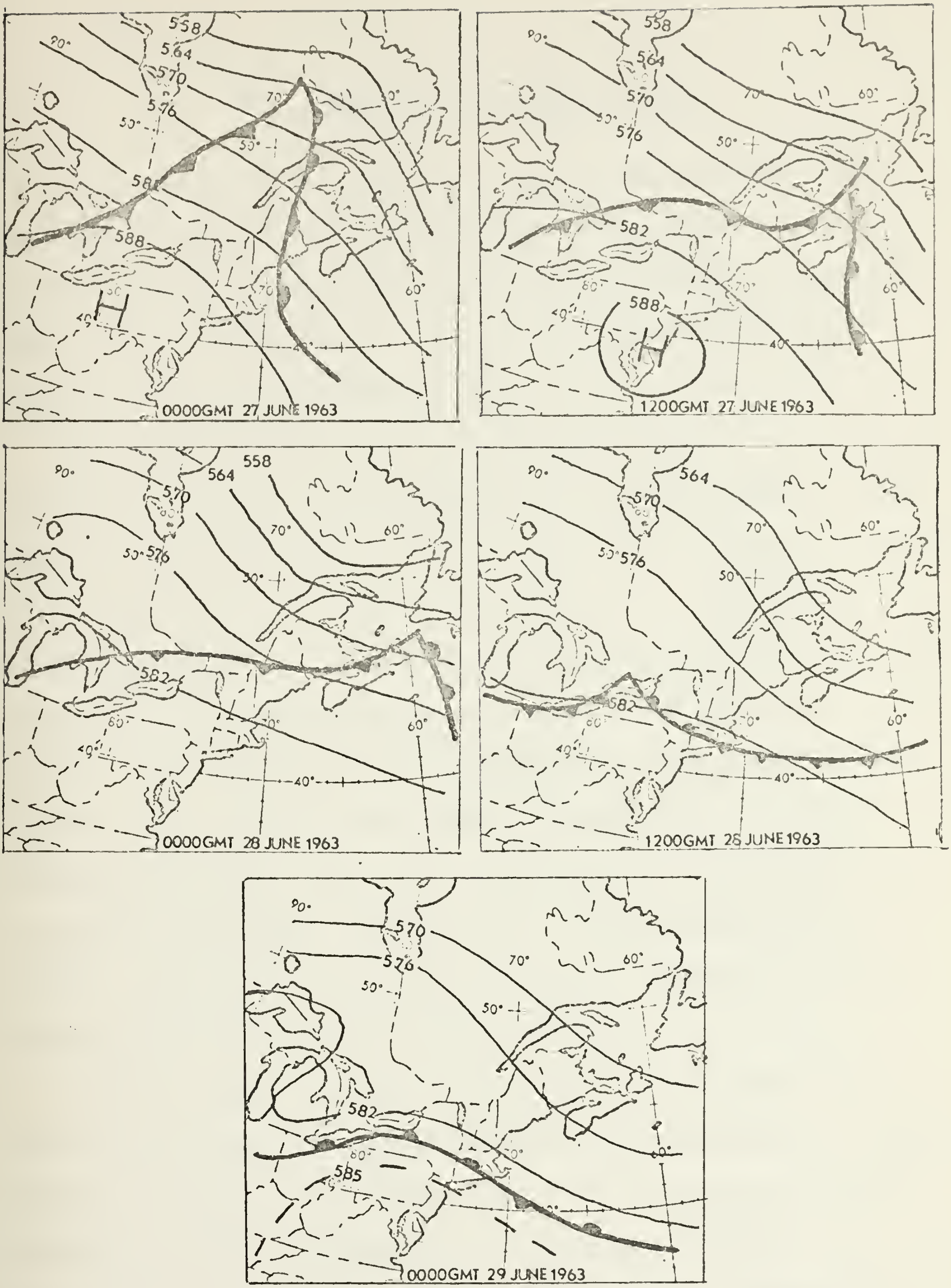

Figure 7. Composite surface frontal positions and 500-mb analyses for the period 0000 GMT 27 June to 0000 GMT 29 June 1963.

V. CASE STUDY: 2 APRIL 1963

The case of 2 April 1963 was selected to illustrate back-door cold fronts. The discussion presents highlights of the synoptic situation and parameter changes associated with the fronts as well as illustrations of pertinent points that were discussed earlier.

The surface analysis for 1200 GMT 12 April 1963 (Figure 8), which is prior to commencement of "backdooring", shows an east-west oriented front along the 47th parallel through northern Maine. A surface high center was located in southern Hudson Bay, and a ridge was oriented from the high center to the Vermont/Canadian border. At 1200 GMT, a 500-mb long-wave trough with north-south orientation was located well off the east coast at about 40W. A 500-mb ridge was located along 90W. The 500-mb flow along the coast was from about 300 degrees. A 500-mb short-wave trough lay north of the surface front imbedded in the northwesterly flow east of the ridge.

From 1200 GMT to 0000 GMT 3 April 1963 (Figure 9) the 500-mb short-wave trough progressed southeastward at approximately 20 knots. The 500-mb ridge and long-wave trough moved gradually eastward with no apparent changes in amplitude. The 500-mb winds along the coast remained from 300 degrees. At the surface during the first six hours of

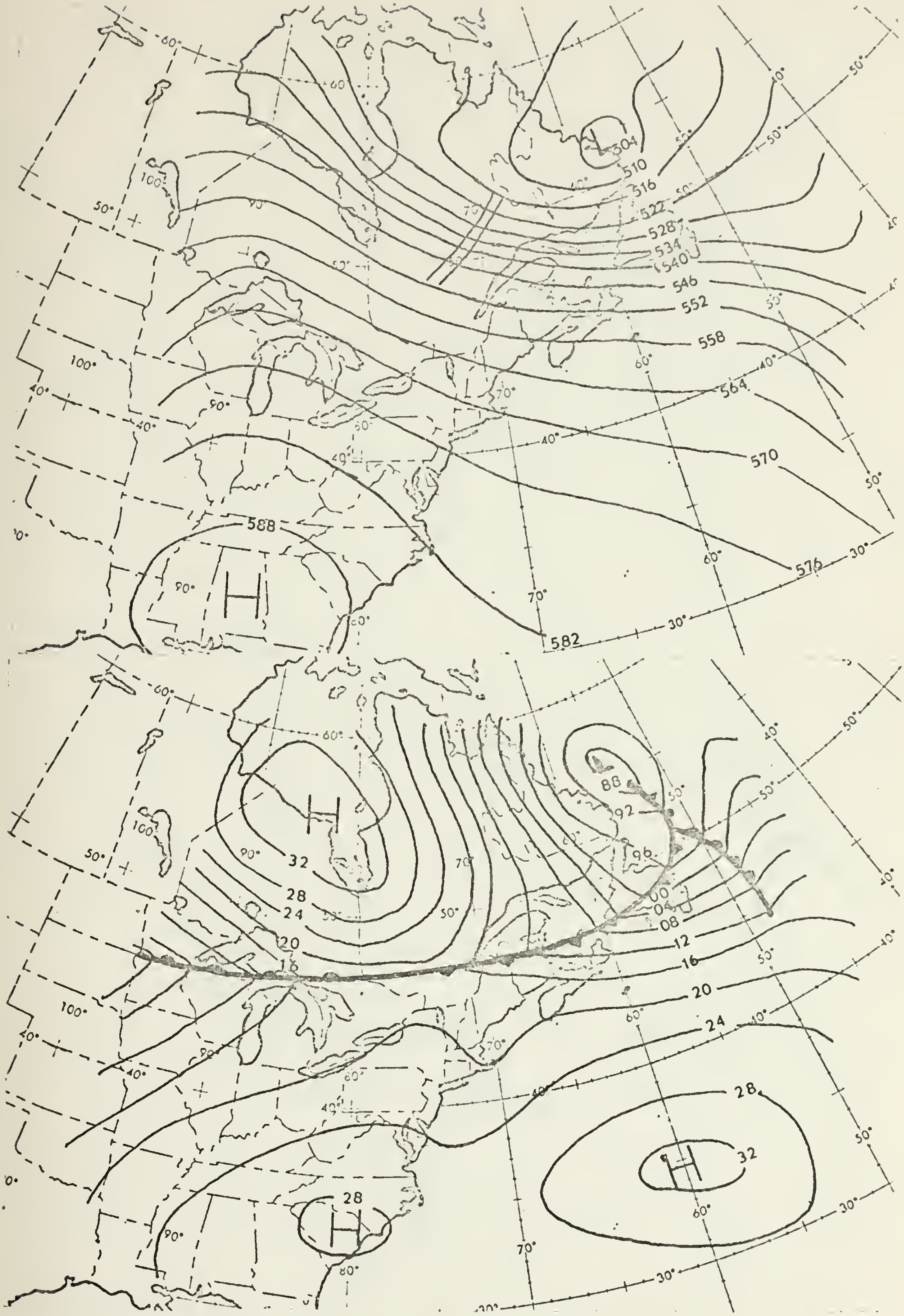

Figure 8. 500 mb and surface analyses, 1200 GMT 2 April 1963.

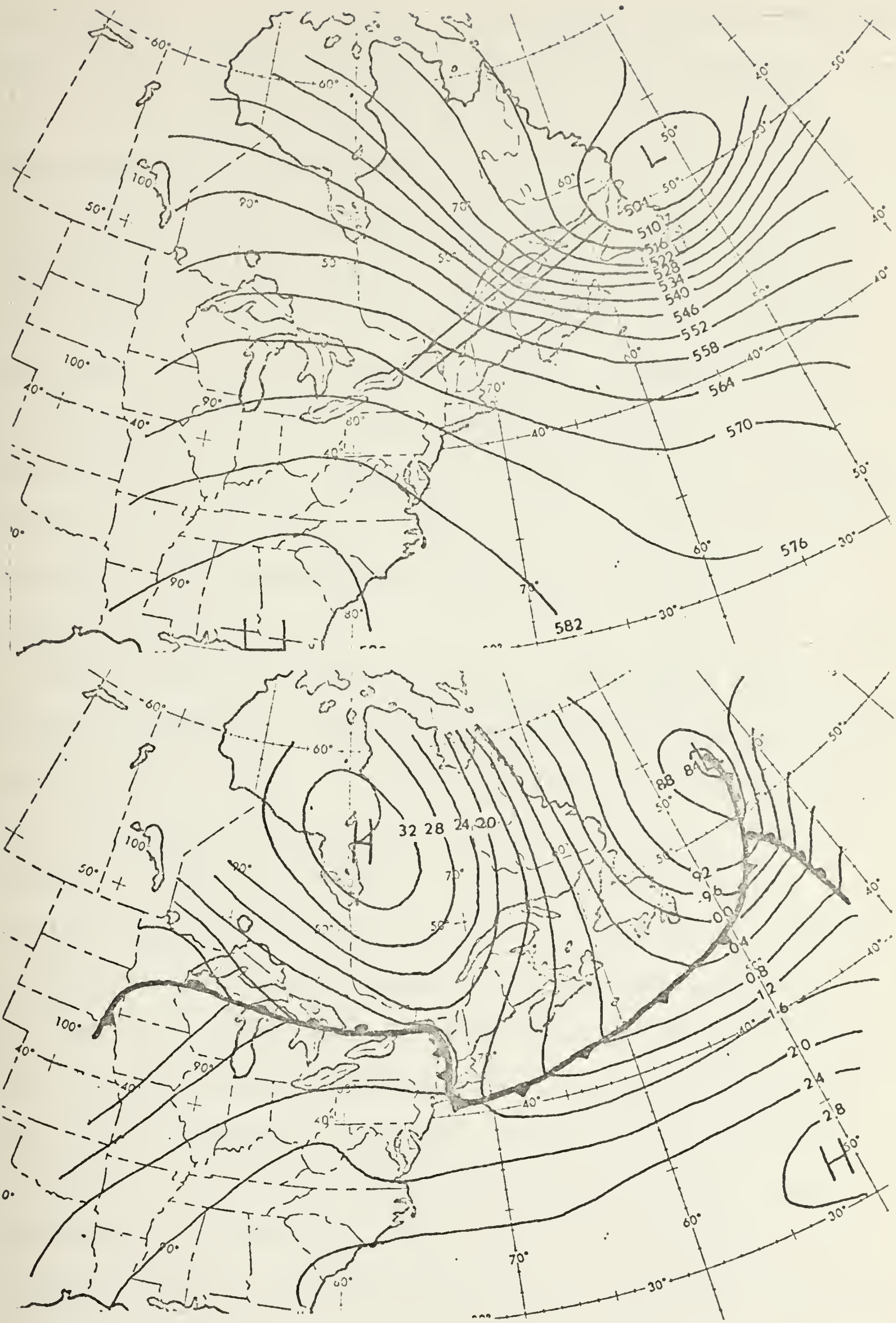

Figure 9. 500 mb and surface analyses, 0000 GMT
3 April 1963.

this period, the front moved southeastward, passing through northern Maine from a "normal" northwesterly direction. The front commenced "backdooring," i.e., began to push southwestward, at approximately 1800 GMT 2 April. In the following six hours the front continued to move southwestward, and by 0000 GMT 3 April its coastal position lay between Hartford and Bridgeport, Connecticut. The westward penetration of the front was stalled by the Appalachian Mountains, such that the front became stationary in the Hudson River Valley. Between 1200 GMT 2 April and 0000 GMT 3 April, the surface analyses show that the high and ridge had moved east-southeastward with some building of the ridge to the southeast.

In the period 1800 GMT 2 April to 0000 GMT 3 April, back-door frontal passages were observed at stations between Bangor and Hartford. Two-hour temperature decreases across the front ranged from 1F at Portland to 8F at several stations. Precipitation did not occur at any of the stations that observed frontal passage. Figure 10 presents, for five stations that observed frontal passages between 1200 GMT 2 April and 0000 GMT 3 April (0700-1900 EST 2 April), three hourly plots of temperature and dew point, pressure and pressure tendencies, winds, and significant weather. In Figure 10, frontal passages occurred between the times separated by an asterisk. The winds at Portland remained southerly prior to and following frontal passage, reflecting

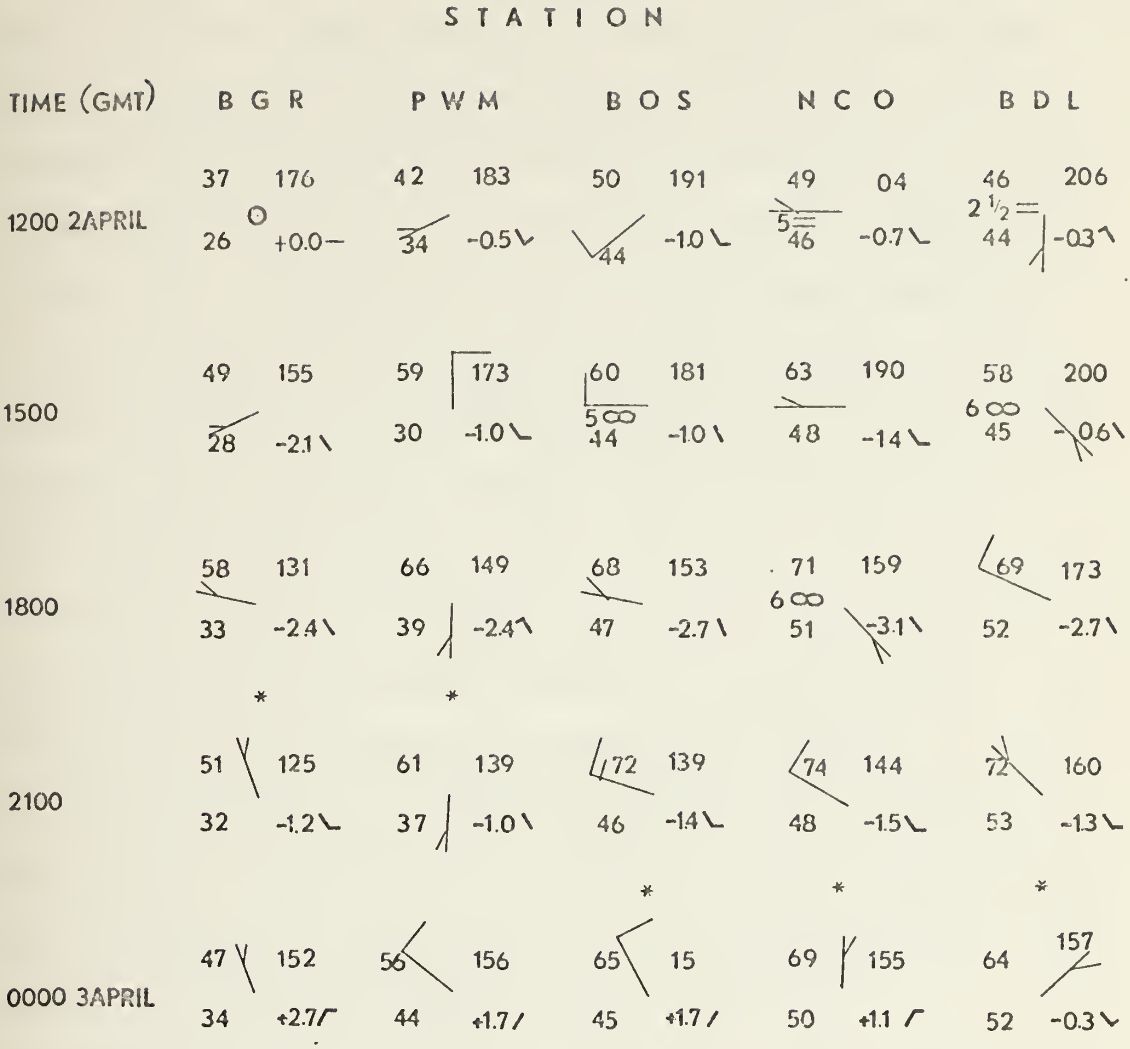

Figure 10. Plot of three hourly weather for 1200 GMT 2 April 1963 to 0000 GMT 3 April 1963.

the dominant influence of a local seabreeze effect. Note also that no significant drop in dew-point temperature occurred at these stations at any times plotted, but significant changes did occur about eight hours following passage (e.g., BGR reported dew-point temperature of 33F at 1800 GMT 2 April, 34F at 0000 GMT 3 April, thence 29F at 0200 GMT, and a minimum of 9F at 1200 GMT 3 April).

At 1200 GMT 3 April (Figure 11), a continued gradual eastward movement of the 500-mb ridge and a reorientation of the long-wave trough closer to the coast are evident. Also, between 0000 GMT and 1200 GMT 3 April, the short-wave trough continued its southeastward movement at about 40 knots, moving through New England and off the coast. The surface high and ridge show southeastward movement, with the ridge continuing to build to the southeast and anticyclogenesis occurring in northeastern Maine. The surface front continued to penetrate to the southwest and lay just south of New York City at 1200 GMT 3 April.

In the period from 0000 to 1200 GMT, cold frontal passages were observed in western Vermont and eastern New York. Two-hour temperature changes across the front ranged from +2F at Suffolk AFB to -10F at Burlington. Figure 12 contains three hourly plots at five stations that observed frontal passage during this period (1900 EST 2 April to 0700 EST 3 April). A striking contrast between frontal passage at inland stations and coastal stations can be

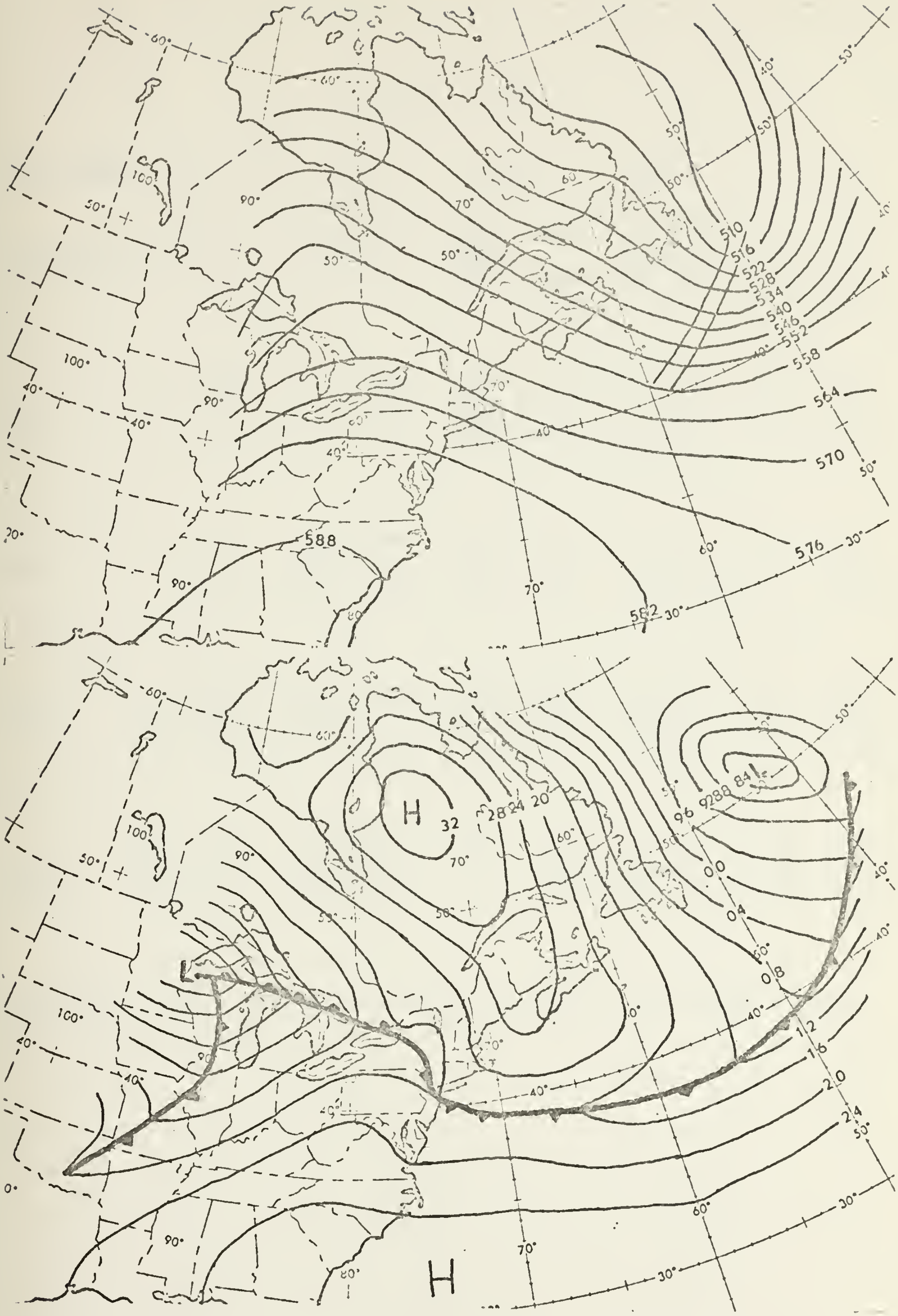

Figure 11. 500 mb and surface analyses, 1200 GMT 3 April 1963.

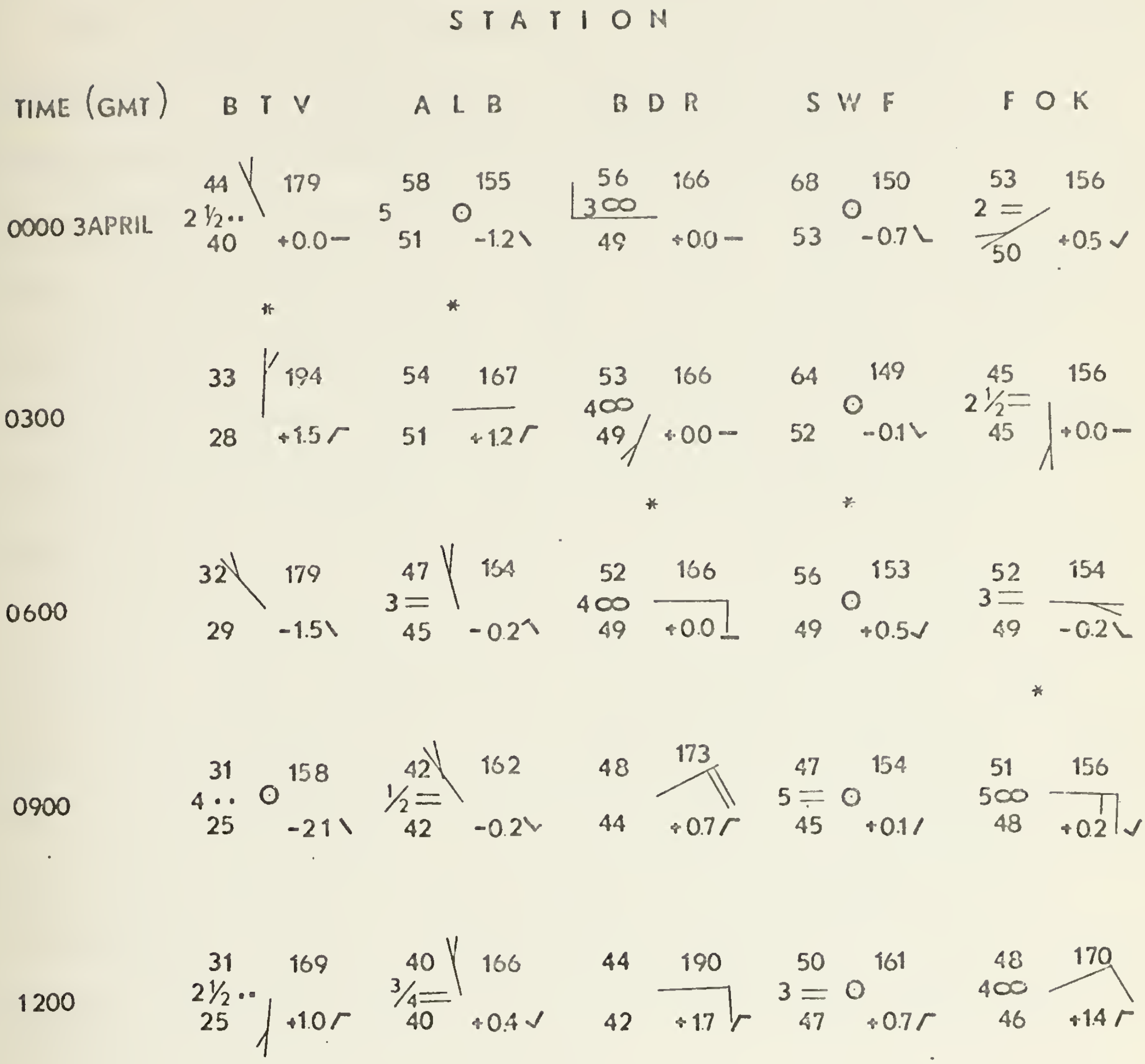

Figure 12. Plot of three hourly weather for 0000 to 1200 GMT 3 April 1963.

seen from comparing frontal parameter changes at Burlington and Suffolk.

Precipitation during the period 0000 to 1200 GMT 3 April was observed at many stations in New England. Figure 13 demonstrates the relationships between the center of maximum precipitation and frontal positions for the five-hour period 0100 to 0600 GMT 3 April. Note that the center of maximum precipitation appears more associated with the passage of the 500-mb trough (Figures 9 and 11) than with the position and motion of the front. The greatest 12-hour total of precipitation for the period was .61 inches at Burlington.

In the following 12-hour period, 1200 GMT 3 April to 0000 GMT 4 April (Figure 14), the 500-mb ridge and long-wave trough commenced a more rapid eastward movement. 500-mb winds along the coast backed to 280 degrees. The new surface high center that developed in northeastern Maine moved southeasterly, with a ridge building down the Atlantic Coast. Further southern penetration of the back-door cold front is evident.

The greatest two-hour temperature changes observed in the case being discussed occurred at stations experiencing frontal passage during the period 1200 GMT 3 April to 0000 GMT 4 April. Decreases of 17F, 22F, and 24F were observed at Lakehurst, Philadelphia, and Willow Grove, respectively. Figure 15 shows the three hourly plots of four stations that observed frontal passage during the period.

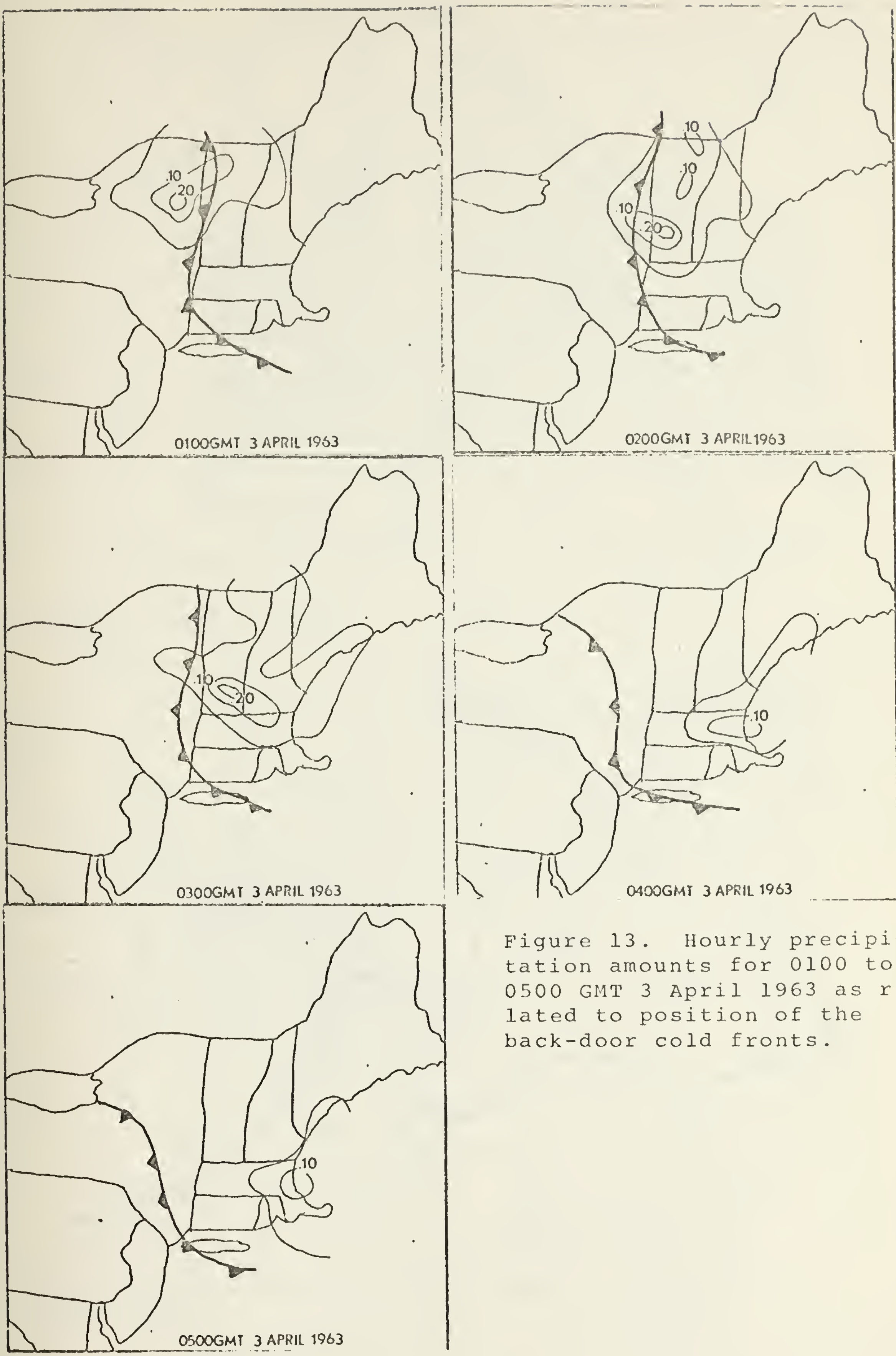

Figure 13. Hourly precipitation amounts for 0100 to 0500 GMT 3 April 1963 as related to position of the back-door cold fronts.

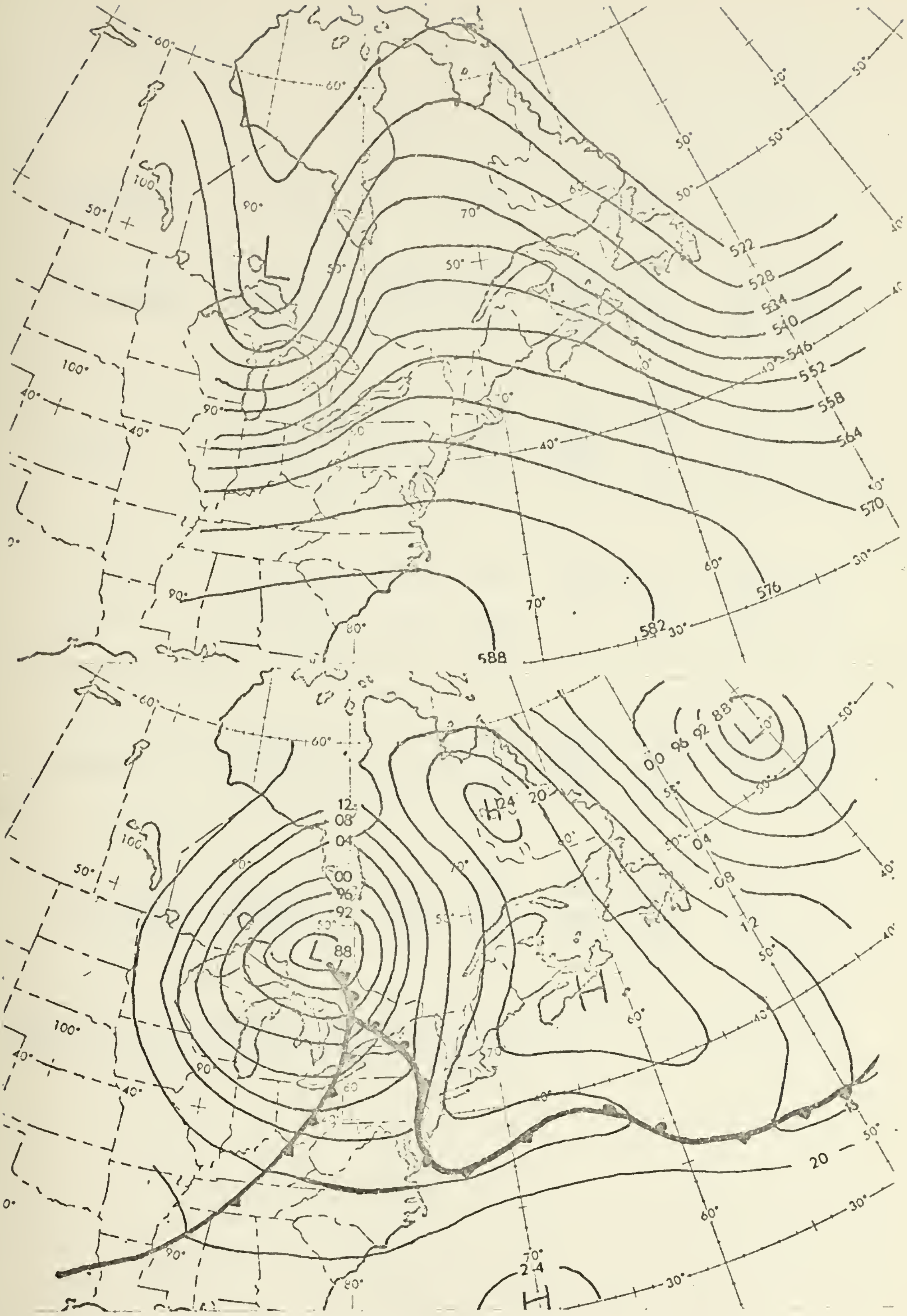

Figure 14. 500 mb and surface analyses, 0000 GMT
4 April 1963.

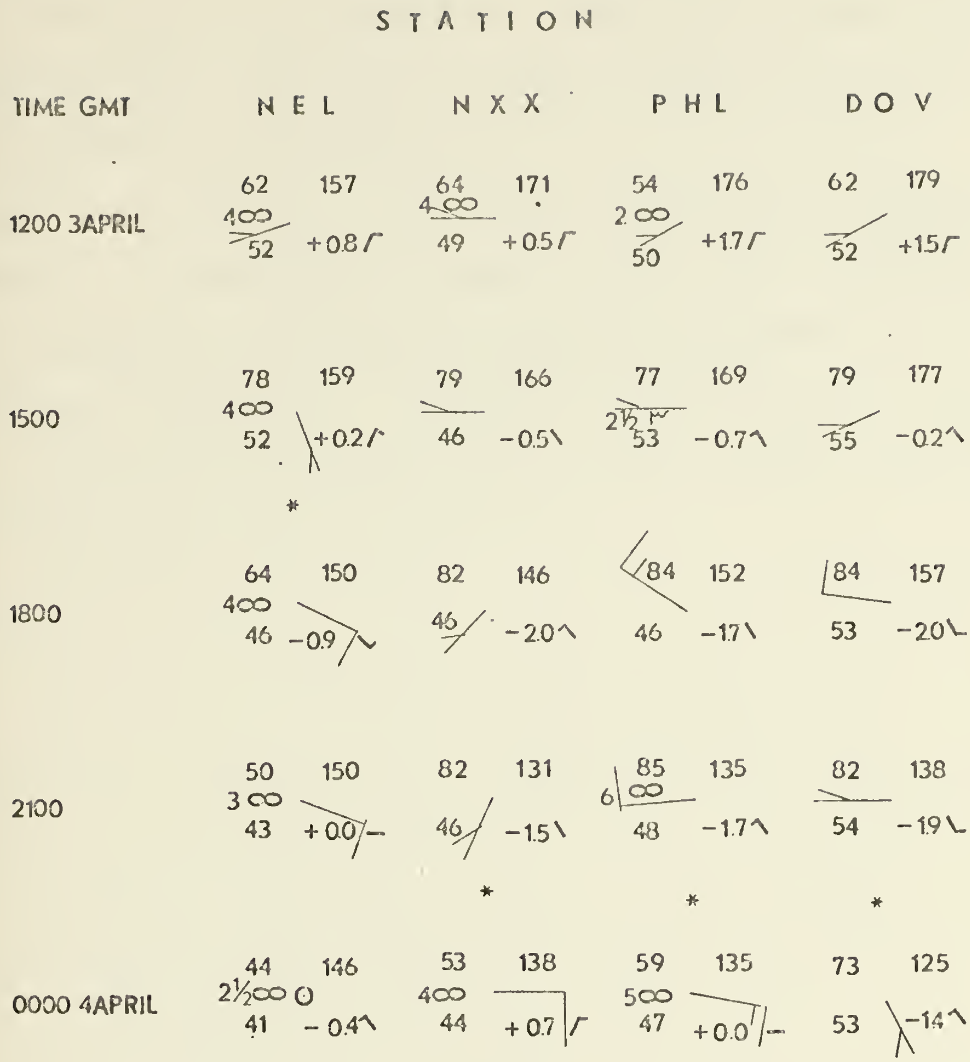

Figure 15. Plots of three hourly weather for 1200 GMT 3 April 1963 to 0000 GMT 4 April 1963.

By 1200 GMT 4 April (Figure 16) the 500-mb ridge has moved offshore, and the front began to return northward along the coast as a warm front. The surface high moved toward the east off the coast, and 500-mb winds along the coast backed to southwesterly.

For the life of the back-door cold front the greatest decreases in daily maximum temperature (23F) occurred in the northernmost stations of Brunswick, Portland, and Portsmouth (Pease AFB). Changes in daily minimum temperature ranged from decreases of 8F in the northern stations to an increase of 2F on Cape Cod.

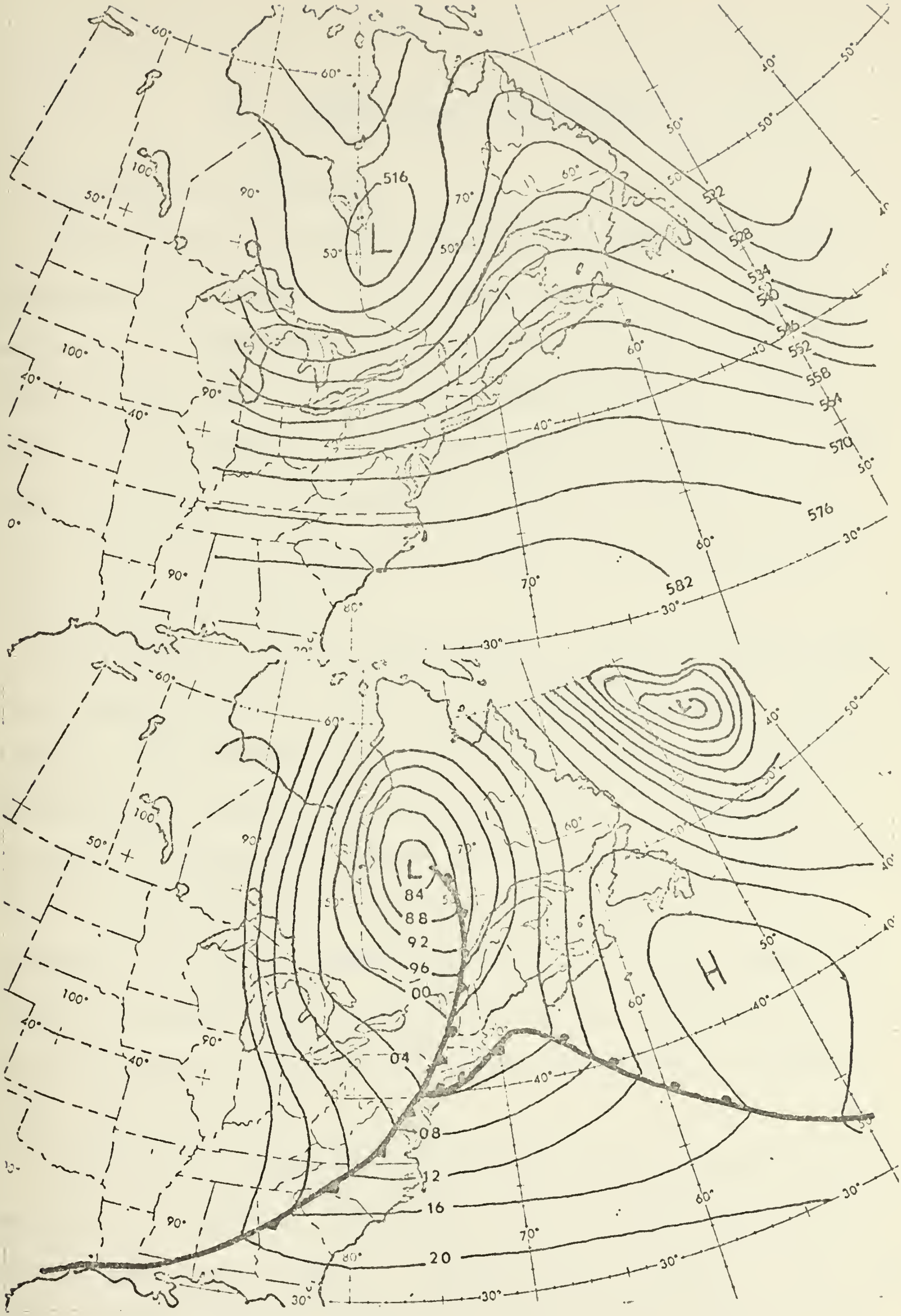

Figure 16. 500 mb and surface analyses, 1200 GMT 4 April 1963.

VI. SUMMARY AND CONCLUSIONS

A. DISCUSSION OF RESULTS

With respect to climatology of back-door cold fronts, the principal results of this research are: 1) highest frequency of occurrence was found in spring and fall; 2) highest occurrence of back-door cold frontal passages is found in New England; 3) deep southern penetration is most likely in June; and 4) average speed of movement is 12 knots with greater speeds occurring in April and October, and in nighttime hours.

With respect to the individuality aspects of back-door cold fronts, it was found that parameter changes across fronts varied widely from case to case as well as station to station. Some notable features are: 1) temperature changes are greater at inland stations than at coastal stations; 2) precipitation is more likely associated with passage of a 500-mb trough than with the frontal position and/or movement, and 3) fronts are shallow with the vertical extent averaging 6000 ft and slope of the front ranging from 1/300 to 1/400.

Although criteria for selection differed from those of Bosart, et al (1973), and Hovey, et al (1967), the results are generally consistent. A point worth noting is that the two previous studies indicated that back-door cold fronts

have a preference to move more rapidly in the period 0000 to 0600 GMT (1900-0100 EST). However, Bosart reflected that this result might possibly be spurious rather than a true synoptic feature of fronts. However, from the results presented earlier in this study and in other reports (e.g., Fleet Weather Facility, Quonset Point, "Forecaster's Handbook" 1968), the preferred rapid movement in nighttime hours does appear to be more fact than spurious. The surface/500-mb relationships in June were notable, and application of the relationships appear to be useful in forecasting the continuance of "backdooring." Although the precise location of fronts in shorter-range forecasts (i.e., $<$ 12 hours) cannot be ascertained from the information presented herein, the general features of the life history of back-door cold fronts can be deduced from the relationships described. Thus, for example, southward penetration should be forecast until: 1) there is an eastward movement off the coast of the high center behind the front, 2) the front becomes parallel to the 500-mb flow, and/or 3) 500-mb winds attain a significant easterly component.

B. SUGGESTIONS FOR FUTURE RESEARCH

This study brought out interesting relationships between the rather shallow back-door cold front and the 500-mb contour pattern. However, the sampling of cases was small

(12 cases), and the choice of a particular month (June) perhaps biased the results. Future research should concentrate on developing specific techniques for forecasting back-door fronts, rather than on the climatological aspects of fronts. Perhaps 12- to 24-hour forecasts of the position of fronts may be obtained from the 500-mb/ surface relationships. The cases in the months of May and June were very similar, as were those in the months of September and October. Using the cases documented in this study or in Bosart, et al (1973) for these two pairs of months, one might obtain from a larger sample of cases more specific forecasting techniques.

Also brought out in this study was the apparent relationship between precipitation and the 500-mb short-wave trough. An extreme example occurred in late August 1973 (not mentioned previously). In that situation, tornadoes were observed in western Massachusetts ahead of a back-door cold front, while at approximately the same time a sharp 500-mb short-wave trough was moving through New England. A more complete investigation is recommended to generalize relationships between back-door cold frontal precipitation and 500-mb short-wave troughs. Specifically, a detailed study of the case of 27 August 1973 is recommended.

LIST OF REFERENCES

1. Bosart, L. F., Pagnotti, V., Lettau, B., "Climatological Aspects of Eastern United States 'Back-Door' Cold Frontal Passages," Monthly Weather Review, 1973, not yet published.

2. Carr, J. A., "The East Coast 'Back-Door' Front of May 16-20, 1951," Monthly Weather Review, v. 79, no. 5, pp. 100-105, May 1951.

3. Hovey, W., Sirinek, K., Storer, F., "A Synoptic Analysis of New England's 'Back-Door' Cold Fronts," Weatherwise, v. 20, no. 6, pp. 264-267, December 1967.

4. Fleet Weather Facility Quonset Point, Rhode Island, Local-Area Forecaster's Handbook, 1968.

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4. TITLE (and Subtitle) Synoptic Investigation of East Coast "Back-Door" Cold Fronts		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis December 1973
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Gordon Allen Bellemer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
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Results are presented from a synoptic study of "back-door" cold fronts along the east coast of the United States in the years 1963 to 1972. The investigation sets forth the climatology of back-door cold fronts with respect to: 1) frequency, 2) six hourly speed of movement, and 3) southern penetration. The individuality of fronts is treated with respect to: 1) temperature and dew-point changes, 2) pressure tendencies, 3) windshifts, 4) precipitation, 5) vertical extent, and 6) surface/500-mb relationships.

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Findings include: 1) highest frequency of occurrence is late spring and early fall, 2) speed of movement is greatest in nighttime hours and in spring and fall, 3) deep southern penetration is most likely to occur in June, 4) precipitation is more associated with a 500-mb short-wave trough and position and/or motion of the surface front, 5) fronts continue southward penetration until parallel to 500-mb flow and 6) southernmost penetration of fronts is coincident with movement of the high center behind (i.e., north of) the front eastward off the coast. A detailed discussion of the 2 April 1963 case is presented.

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